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ANALYSIS OF FIRE HAZARDS AND RISKS IN FRONT RANGE FORESTS OF COLORADO

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by

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Report to Rocky Mountain Forest and Range Experiment Station
U.S. Forest Service

by

Colorado State University
Department of Forest and Wood Sciences
1975

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Contents

	Page
Introduction	1
Research Objectives	7
Research Methods	8
Fire Analysis	8
Fuel Studies	10
The Front Range Forests	16
Analysis of Forest Fire Hazards	24
Forest Cover Types	24
Fuel Types	33
Inventory and Analysis of Fuels	38
Analysis of Forest Fire Risks	44
Risk Characteristics	44
Lightning Fires	44
Man-caused Fires	47
Integrated Analysis of Fire Hazards and Risks	51
Fire Load	51
Forest Fire Potential	51
Literature Cited	57

ANALYSIS OF FIRE HAZARDS AND RISKS IN FRONT RANGE FORESTS OF COLORADO

by

Kevin C. Ryan and Jack S. Barrows[1]

INTRODUCTION

Following World War II, the State of Colorado experienced dynamic population growth. The U.S. Census Bureau estimates that the population of the State increased 89.3 percent between 1950 and 1972. The greatest growth has been in the Front Range area including the immediately adjacent high plains counties. In Colorado Planning Regions 2, 3, 4, 7, 8 and 13 (Figure 1), which encompass the Front Range forests, population increased 99.0 percent between 1950 and 1972 (Table 1). During the same period population increased 113.9 percent in the greater Denver area (Region 2) and 235.3 percent in the Colorado Springs area (Region 4).

Accompanying this spectacular growth there has been a great increase in the development and use of the Front Range forest resources. New communities and recreation areas have emerged in many parts of the mountain country. Both Colorado residents and thousands of visitors from other regions of the country are utilizing the forest areas for a variety of recreational and economic purposes. In addition, these forest areas provide critically important watersheds that are the life blood of the Colorado economy. About 85 percent of the state's annual runoff originates from the mountain forests and areas above timberline (Miller and Choate, 1964).

Forest fires have always been an important element in the Colorado forest resource scene. Since the end of World War II there has been a 270 percent increase in the number of fires in Colorado forests (Figure 2). During the

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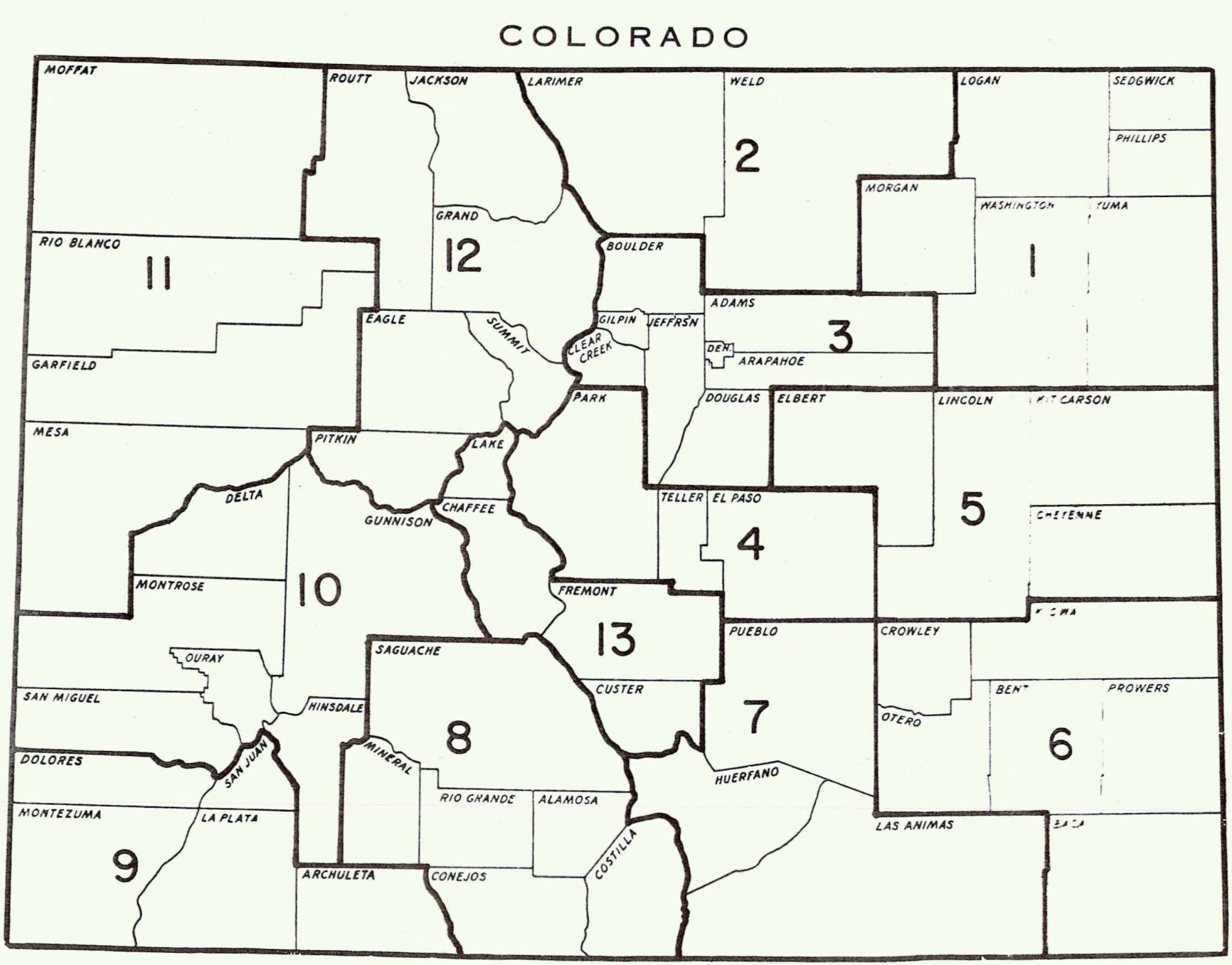


Figure 1. Colorado Planning Regions

Table 1. Summary of Colorado Population Growth in General Front Range Area.

Planning Region	Total Pop. 1950	Total Pop. 1960	% Pop. Change 1950-1960	Total Pop. 1970	% Pop. Change 1960-1970	Total Pop. Est. 1972	% Pop. Change 1970-1972	Total % Change 1950-1972
Region 2	111,058	125,687	13.2	179,197	42.6	204,543	14.1	84.2
Region 3	612,774	937,677	51.3	1,242,027	32.5	1,325,400	6.7	113.9
Region 4	79,184	148,049	87.1	241,441	63.1	265,500	10.0	235.3
Region 7	126,639	146,557	15.7	140,572	- 4.1	143,000	1.7	12.9
Region 8	45,963	38,704	-15.8	37,466	- 3.2	38,563	2.0	- 16.1
Region 13	33,257	36,900	11.0	41,506	12.5	44,600	7.5	34.1
Total All Regions	1,015,875	1,433,584	41.1	1,882,209	31.3	2,021,606	7.4	99.0

period 1946-1973 more than 328,000 acres were burned (Figure 3). In view of the increased pressures on Colorado's forest resources and the potential impacts of forest fires, it became apparent that an in-depth analysis of forest fire hazard and risk was needed. In response to this need, Colorado State University under the sponsorship of the Eisenhower Consortium (Rocky Mountain Forest and Range Experiment Station Agreement Number 16-359-CA) initiated research of these factors in 1973.

This report presents the results of an exploratory study of forest fire hazards and risks in selected forest areas of the Front Range. This initial study is the first phase of a research effort that will eventually examine fire hazards and risks throughout Colorado. In Phase I, study efforts have been concentrated on the general nature of forest fire hazards and risks. Analysis has been performed on an array of fuel and topographic features which constitute a forest fire hazard and on the ignition factors which make up forest fire risk in Front Range forests.

Figure 2

AVERAGE ANNUAL NUMBER OF FIRES IN COLORADO BY FOUR YEAR PERIODS 1946-1973

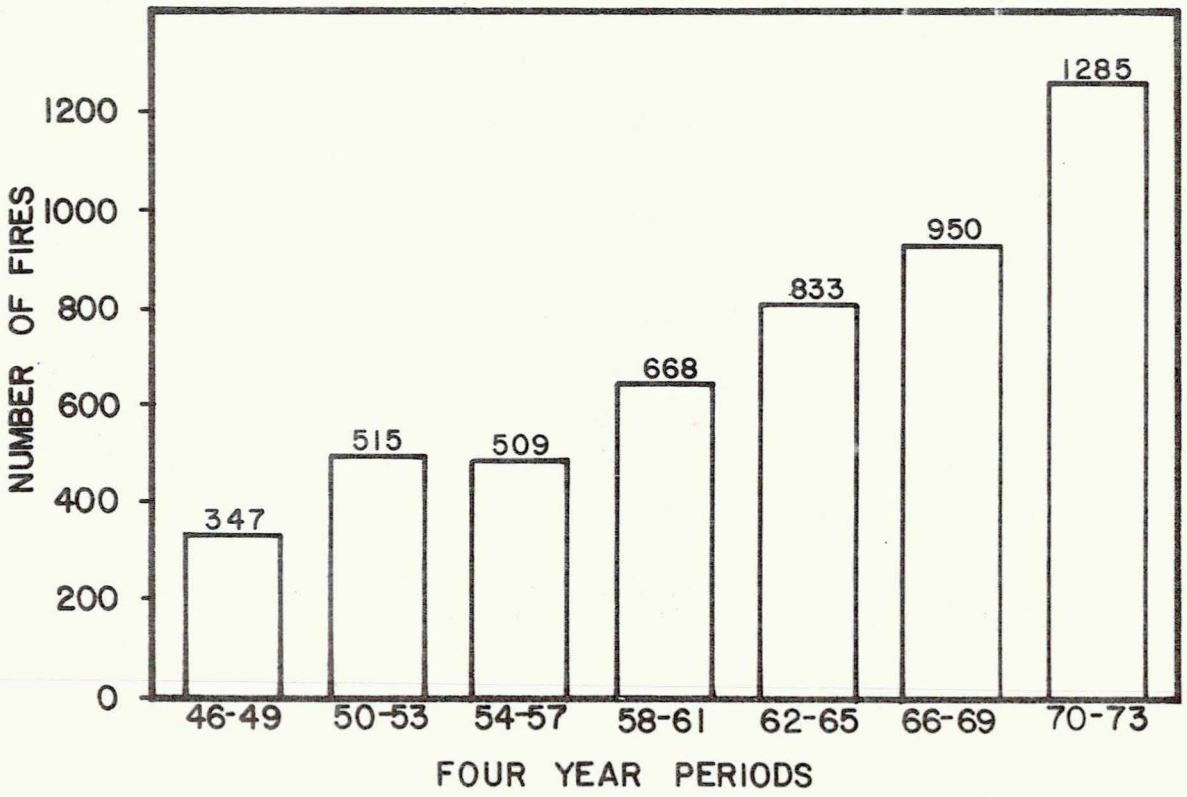
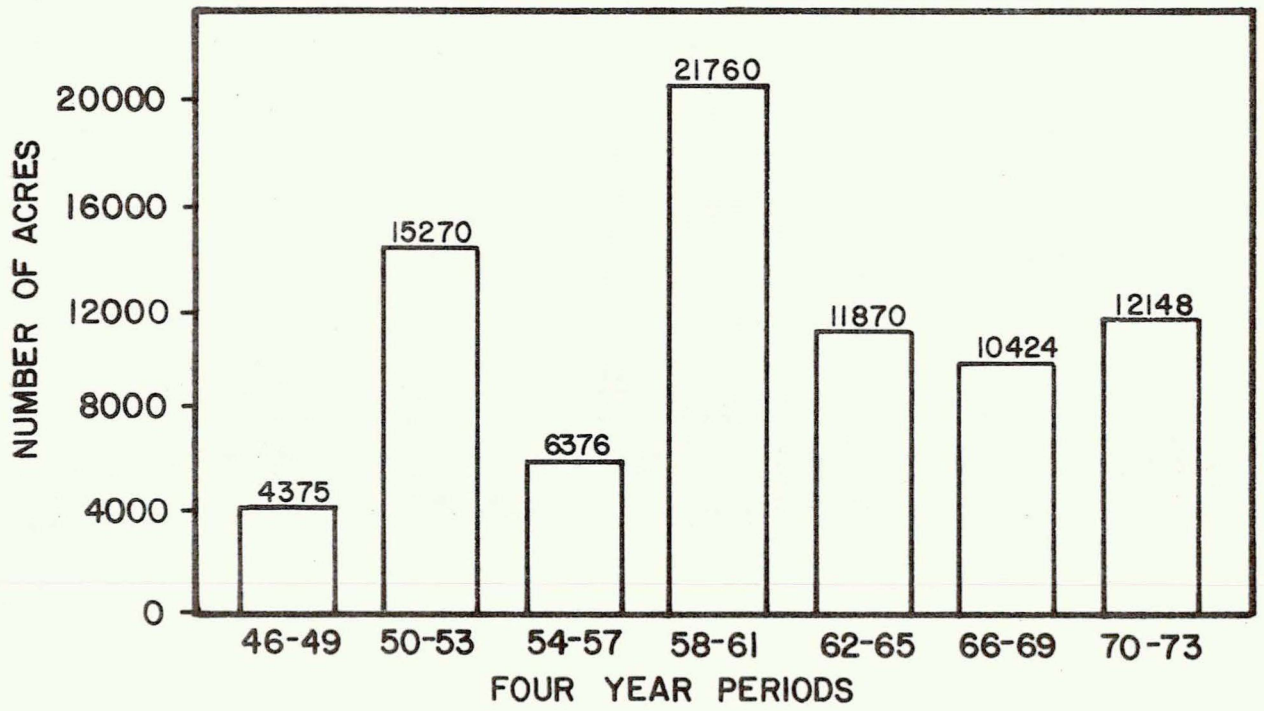


Figure 3

AVERAGE NUMBER OF ACRES BURNED IN
COLORADO BY FOUR YEAR PERIODS 1946-1973



(TOTAL ACRES BURNED 328,892)

RESEARCH OBJECTIVES

The specific objectives of the Phase I study are to:

1. Analyze trends and consequences of wildfires that have burned in various fuels and under various conditions common to the Front Range.
2. Identify Front Range Fuel and Topographic situations that provide serious potential for ignition and initial fire growth.
3. Identify the characteristics of both forest fire hazard and risk that have impact on the protection and management of forest resources and on the safety of the public utilizing these resources.
4. Enhance the understanding of hazard and risk factors which are essential for planning, management and fire prevention and control.

These objectives were established for the purpose of developing basic hazard and risk information needed in the interrelated fields of forest fire management and land use planning. The main thrust of this research has been to gain an improved understanding of several features of forest fire hazard and risk and to relate these features to management actions.

RESEARCH METHODS

The exploratory nature of this research coupled with limited time and resources for the work provided severe constraints for the undertaking. These constraints dictated an approach which made maximum use of readily available data and limited acquisition of new field data. However, in spite of these constraints the investigators found promising opportunities for analysis of forest fire hazards and risks.

The research approach involved the following principal areas of study:

1. Review of the fire history in Front Range forests.
2. Analysis of forest fire hazards.
3. Analysis of forest fire risks.
4. Inventory and analysis of fuels.
5. Integrated analysis of forest fire hazards and risks.

Fire Analyses

Fire History

A general review of fire history was accomplished primarily through examination of the official fire reports of the various state and federal forest fire control agencies. The period 1946-1973 was used for this general review. Annual Clarke-McNary fire reports published by the U.S. Forest Service provided the history of fire occurrence and area burned on private, state and federal lands (U.S. Forest Service (b)). These reports were supplemented by examination of annual National Forest Fire Reports for the five Front Range national forests (U.S. Forest Service (a)).

The general fire history studies were extended to provide preliminary insight into forest fire hazards and risks. Statistical analysis was used to

determine trends of fire occurrence and area burned by major cause. These trends were analyzed for broad areas of the Front Range having a wide variety of forest conditions and patterns of use.

Fire Hazards

The best available data for study of forest fire hazards are the U.S. Forest Service individual Fire Reports (5100-29). For each fire the specific hazard factors of topography, forest cover type and fuel type are recorded in a standard manner. To provide a representative sample of these factors in the Front Range the individual fire reports for the Arapaho, Pike, Rio Grande, Roosevelt and San Isabel National Forests were analyzed for the period 1960-1972. Special computer programs were developed for analysis of hazard factors on 2,130 fires in the sample. Fire performance in terms of ignition rates, size class of fires, and area burned was used to evaluate the hazard factors.

The study of hazards on individual fires was supplemented by a field inventory of fuels in a representative Front Range forest. Research methods for this phase of the anaylysis are described in the fuel studies section.

Analysis of fire hazards for the total Front Range forest area would require examination of the fire reports from all forest protection agencies. However, in this limited preliminary study it was not possible to obtain suitable data on individual fires from all agencies and to organize these data in the formats required for computer processing. The data for the National Forests provides a large sample, but obviously does not represent all Front Range fire conditions.

Fire Risks

Following the pattern used in the fire hazard studies, individual fire reports provided the major data base for statistical analysis of forest fire

risks. The study concentrated on the occurrence of both lightning and man-caused fires under specific forest environments and locations during the period 1960-1972. Computer programs were developed for analyzing risk factors on actual fires. In addition, U.S. Census bureau population data and U.S. Forest Service visitor use reports were also used in the analysis of man-caused risk levels. The main thrust of the analysis was to identify significant patterns and densities of fire occurrence in accordance with factors of ignition source, forest environment and forest use.

Fuel Studies

Stand Selection

Potential areas to be inventories were located on Wildfire Hazard Area Maps prepared by the Colorado State Forest Service. The maps are delineated into three hazard classes based on percent crown closure as determined from aerial photographs.

The three hazard classes are:

1. Class A: Low Hazard - Trees and Grass
   (0 - 35% Crown Closure)

2. Class B: Medium Hazard - Trees
   (35 - 55% Crown Closure)

3. Class C: Severe Hazard - Trees
   (over 55% Crown Closure)

There are other Hazard Classes in the Colorado State Forest Service mapping system (Colorado State Forest Service, 1974), but they are not represented in the study area west of Boulder, Colorado. The reader should refer to the "Guidelines and Criteria for Wildfire Hazard Areas" (September, 1974) prepared by the Colorado State Forest Service for a more complete description of these Hazard Classes.

Once the potential areas had been located on the map they were located in the field and visually determined to be in the hazard class which had been mapped. To qualify as a stand for inventory the area had to be homogeneous over an area large enough to be sampled by a uniform grid of at least twenty fuel plot transects.

Within each hazard class stands were located in a variety of forest cover types. Ecosystem Maps prepared by the Colorado State Forest Service and Timber Type Maps prepared by the U.S. Forest Service were used to aid in locating forest cover types in each hazard class.

There were three forest cover types which predominated in the study area. These are:

1) Ponderosa pine (This designation was used both for open grown stands in which herbaceous vegetation is the primary carrier of a surface fire and closed stands in which needles and branchwood are the primary carriers of a surface fire.)

2) Douglas-fir (This designation was restricted to pure stands of Douglas-fir.)

3) mixed conifer (This designation was used for stands which contained a mixture of ponderosa pine and Douglas-fir with neither species making up 80% or more of the tree cover.)

Stands were also located in a variety of topographic conditions with respect to elevation, aspect, and slope.

Stand Information

Information and data, relating primarily to stand characteristics, were collected for each stand. Stand information included the stand's location, elevation, aspect, physiography, species composition, stocking and structure. Stand location was recorded by both legal description (to the nearest 1/4 section) and land mark description. The average stand elevation was taken from U.S.G.S. 7 1/2-minute Quadrangle maps and recorded to the nearest 100 feet. Average stand aspect was coded as follows:

1 - level
2 - north
3 - northeast
4 - east
5 - southeast
6 - south
7 - southwest
8 - west
9 - northwest

Stand physiography was coded for both slope position and slope configuration. Slope position was coded as follows:

1 - stream bottom/basin
2 - bench/flat
3 - lower slope
4 - mid slope
5 - upper slope
6 - ridge top

Slope configuration was coded as follows:

1 - Convex (5 = 175°)
2 - Straight (176 - 185°)
3 - Concave (186 - 355°)
4 - Undulating

The composition of the forest vegetation was coded for the two dominant tree species in the stand and the two major components of the fuel bed at each plot. The following codes were used:

1 - ponderosa pine
2 - Douglas-fir
3 - mixed conifer
4 - aspen
5 - herbaceous

Stand stocking was coded as follows:

1 - sapling - poor
2 - sapling - medium
3 - sapling - well
4 - pole - poor
5 - pole - medium
6 - pole - well
7 - mature - poor
8 - mature - medium
9 - mature - well

Where possible U.S. Forest Service Timber Type Maps were used to aid in making a determination of stocking levels.

Stand Structure was coded as follows:

1 - single-storied
2 - bi-storied
3 - tri-storied
4 - multi-storied

In addition stand fuel calssification was recorded for each of three fuel classification systems. The three are: 1) the Colorado State Forest Service Wildfire Hazard Area Mapping System (Colorado State Forest Service, 1974); 2) the National Fire Danger Rating System Fuel Models (Deeming, et al., 1972); and 3) Rate of Spread/Resistance to Control Fuel Type classification system. The Rate of Spread/Resistance to Control designation followed the low, medium, high, and extreme systems used on the U.S. Forest Service Region 2 Fire Report Forms (U.S. Forest Service, 1960).

Stand Measurements

Within each stand a minimum of ten trees in the dominant crown class were selected for measurement of tree height, diameter, and age. This information will be used to determine site index. The distance to the base of the living crown was also measured. This will provide a measure of vertical fuel continuity and crown fire potential. In addition to the ten dominant

trees, fire scarred trees were measured in some stands. This will give a more complete picture of stand history. Although all stands had visible signs of past fire, surviving trees with visible fire scars were not found in some stands. Additional stand information included clipping herbaceous vegetation for oven drying and weighing and the taking of basal area measurements at each plot center. A separate tally was kept for the number of count trees and count snags.

Plot Location and Configuration

Within each stand a minimum of twenty fuel inventory plots were located at fixed intervals along regularly spaced transects. The location of the first plot in the uniform sampling grid was random. The grid consisted of from two to five parallel transects with a minimum of five plots per transect. The number of transects and plots and the distance between the transects and plots was determined from ocular evaluation of stand size and shape. All distances between transects and plots were paced along compass lines.

Since it is hoped that information from these fuel inventory plots will add "ground truth" input into the Colorado State Forest Service's Wildfire Hazard Area Mapping system care was taken to insure that all fuel inventory plots remained well within a single hazard class. Transition zones were avoided to reduce the variability within stands and increase the predictability of fuel loadings in hazard classes.

Plot Description

A plot consisted of a verticle 6 foot high planar transect. The center of the plot was located on the major transect which traversed the stand. The azmuth of the plot transect was selected from a table of random numbers. Plots

were denoted on the ground by running a steel engineer's tape from the plot center parallel to the ground in the random direction.

Phase sampling of each of the fuel size classes was utilized in the plot transects. The length of the transect required for each size class is dependent upon the variation in that class. In these initial studies the minimum transect length for each fuel size class was:

6.8 feet for fuel particles less than 3 inches in diameter (this includes 3 fuel-size classes),

50.0 feet for fuel particles greater than 3 inches in diameter.

A 6.8 foot transect was found to be long enough to adequately sample fuel particles in the 0 to .25 inch and the .25 to 1.0 inch size classes in most cases. Longer transects were used for the two larger size classes when the number of sampling planes which failed to intersect fuel particles exceeded 25%. When sampling planes longer than 50 feet were required to adequately sample the over 3 inch size classes multiple 50 foot sample planes were used. Successive sample planes radiated from the plot center in an ordered manner. Multiple sampling planes were used to reduce the amount of variation on any one plot.

Plot Procedures

The fuel inventory methods used on the sample plots closely followed those developed by Dr. James K. Brown of the Northern Forest Fire Laboratory, Missoula, Montana (1974). Additional data collected included measuring the diameter of snags in a 6 foot wide belt transect centered over the greater than 3 inch fuel inventory transect, clipping herbaceous vegetation from one meter square quadrats, estimating the height to the base of the living crown, and measuring the basal area.

THE FRONT RANGE FORESTS

The Front Range area of Colorado encompasses some 14 million acres extending from the foothills to the Continental Divide. For the purposes of this study the area also includes those portions of the five Front Range National Forests that extend west of the Continental Divide.

The forest areas of the Front Range are highly diverse in character. The major forest cover types are ponderosa pine, lodgepole pine, Engelmann spruce, Douglas-fir, pinyon-juniper, and quaking aspen. Other cover types include alpine fir, white fir, subalpine type, white pine group, and brush and grass. All species listed on tables and graphs in this report correspond to the forest cover types in the U.S. Forest Service Region 2 Individual Fire Report Handbook (1960).

In the Front Range elevations range from 5,000 to more than 14,000 feet above sea level. Accompanying this marked variation in elevation is an equally marked change in environmental factors and a resultant zonation of vegetation (Daubenmire, 1943). In the Front Range there are five broad vegetation zones related to elevation. The five zones and their approximate elevations are: the plains zone (below 6,000 feet), the foothills zone (6,000 to 8,000 feet), the montane zone (8,000 to 10,000 feet), the subalpine zone (10,000 to 11,500 feet) and the alpine zone (above 11,500 feet) (Kelly, 1970). These zones are not always continuous nor are they always present (Oosting, 1956). In the northern portion of the State the foothills zone runs out and the upper zones are found at relatively lower elevations. Southward all zones are found at somewhat higher elevations and the lower zones become broader (Oosting, 1956).

Because the Front Range is on the lee side of the Continental Divide there is considerable variation in the vegetation of all zones regardless of latitude. North and south exposures produce marked irregularities in climax

vegetation. On north facing slopes the dominants of one zone extend downward into a lower zone. On south facing slopes and dry ridge-tops, dominants of one zone extend upward into higher zones (Oosting, 1956). A corresponding variation in the fire environments of the Front Range can be expected with these changes in elevation and aspect.

The lowest zone, the plains, is characterized by short-grass prairie species such as blue gramma (*Bouteloua gracilis*), buffalograss (*Buchloe dactyloides*), needle-and-thread (*Stipa comata*), bluestem (*Agropyron smithii*), and red-tree-awn (*Aristada longiseta*) (Oosting, 1956). Depending upon local conditions the short-grass prairie extends upward into the Front Range. These grasslands have a moderate potential for wildfire. Fires in this type normally do not spread rapidly until the vegetation has cured. Then depending on continuity, slope and wind they may be very flashy (Barrows, 1951a). Under windy conditions even patchy grass fuels may have very high rates of spread (Rothermel, 1972). Grassland fires are typically low intensity fires and are easily controlled except when there is an abnormally high rate of spread.

To the west the plains merge with the foothills zone. In the southern part of the State this zone is characterized by a climax of pinyon pine (*Pinus edulis*) and Rocky Mountain juniper (*Juniperus scopulorum*). This vegetation type is typified by a forest of widely spaced small trees with limbs extending to the ground. This condition creates an excellent "fuel ladder" (Lynch, 1974). The understory vegetation is typically that of the short-grass prairie (Oosting, 1956) and the condition of the understory has a most pronounced effect on wildfire potential (Lynch, 1974).

The pinyon-juniper type occurs at elevations ranging from 5,500 to 7,000 feet and is common as far north as Colorado Springs, Colorado. Farther north pinyon pine drops out except for an isolated occurrence near Livermore, Colorado (Daubenmire, 1943).

On some sites in the foothills zone Gambel's oak (*Quercus gambelii*) and mountain mahogany (*Cercocarpus montanus*) form a climax mountain shrub community. Like the pinyon-juniper type the oakbush-mountain mahogany community is best developed in the southern part of the state. The community narrows and becomes discontinuous farther north with Gambel's oak dropping out north of Denver, Colorado (Daubenmire, 1943). North of Denver mountain mahogany dominates the narrow mountain shrub zone on the lower slopes of the hogbacks with ponderosa pine (*Pinus ponderosa*) dominating the ridges above 6,000 feet (Costello, 1964). Fires in the shrub community can have high rates of spread especially when the grass understory has cured (Barrows, 1951a). The intensity of fires in the mountain shrub community is dependant upon the density and height of the brush (Lynch, 1974).

Ponderosa pine and Douglas-fir (*Pseudotsuga menziesii*) are prominent throughout the upper range of the foothill zone in the Front Range. Ponderosa pine is found at elevations ranging from 5,000 to 9,000 feet. It often grows in open stands with a rich understory of bunch grasses (*Festuca* spp.), mountain muhly (*Mulenbergia montana*), cheatgrass (*Bromus tectorum*), and prairie beardgrass (*Andropogon scoparius*) (Costello, 1964). At lower elevations ponderosa pine is climax on north facing slopes (Oosting, 1956). At higher elevations it is mainly restricted to the dry south facing slopes and ridge tops (Oosting, 1956).

Wildfire potential in the ponderosa pine is dependant upon stand conditions. Open grown stands on south facing slopes may have very high rates of spread depending on the condition of the understory vegetation, slope and wind (Barrows, 1951a). Fires in these stands are usually restricted to the herbaceous understory and are usually of low intensity. They seldom cause mortality to mature trees (Daubenmire, 1943). On north facing slopes

stands are usually much denser. The understory is protected from intense solar insolation and drying. As a result fires in these denser stands usually exhibit lower rates of spread than the more open stands. However, fires in these stands are much more intense. Crown fire potential is also increased due to dense reproduction and low crowns. Near its upper altitudinal range ponderosa pine is generally replaced following fire by lodgepole pine (*Pinus contorta*) in the northern part of the state (Oosting, 1956) and quaking aspen (*Populus tremuloides*) in the southern part of the state (Costello, 1964).

There are approximately 503,000 acres of ponderosa pine in the five Front Range National Forests (Table 4).

Douglas-fir is found at elevations ranging from 6,000 to 11,000 feet in the Front Range. It is restricted to north facing slopes at its lower elevational limit in the foothill zone and to south facing slopes at its upper limit in the subalpine zone. Between these elevational extremes is a broad transition zone where ponderosa pine and Douglas-fir share dominance (Oosting, 1956). In general ponderosa pine is the climax species below 7,000 feet and Douglas-fir is climax above 8,000 feet in the montane zone (Oosting, 1956). Other species commonly associated with Douglas-fir communities include common juniper (*Juniperus communis*), kinnikinnic (*Arctostaphylos uva-ursi*), cliff jamesia (*Jamesia americana*), and Fremont geramium (*Geranium fremontii*) (Zuck, 1974). Douglas-fir often grows in such dense stands that subordinate vegetation is negligible (Oosting, 1956).

Because ground fuels are shaded, rate of spread is usually moderate. However, large amounts of fine fuels are usually present and reproduction is usually good resulting in a high crownfire potential during periods of high fire danger. Ponderosa pine usually pioneers after fires at the lower elevations and lodgepole pine and quaking aspen are pioneers at the middle and upper elevations in the Douglas-fir zone.

There are approximately 475,000 acres of Douglas fir in the five Front Range National Forests (Table 4).

The subalpine zone is often referred to as the spruce-fir zone because of the predominance of Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*). The spruce-fir extends from 8,500 feet up to timberline which ranges from 11,500 feet in northern Colorado to 12,000 feet in southern Colorado (Costello, 1964). Near timberline and on dry rocky ridges subalpine fir drops out and Engelmann spruce forms a Krummholz forest of distorted dwarf trees (Daubenmire, 1943). Other species also found with spruce on these harsh windswept sites are limber pine (*Pinus flexilis*) and bristlecone pine (*Pinus aristata*).

Below the Krummholz area Engelmann spruce and subalpine fir form dense stands (Oosting, 1956). Common understory species in spruce-fir communities include myrtle whortleberry (*Vaccinium myrtillus*), grouse whortleberry (*Vaccinium scoparius*), heartleaf arnica (*Arnica cordifolia*), pyrola (*Pyrola* spp.) and rose (*Rosa* spp.) (Zuck, 1974).

Although Engelmann spruce and subalpine fir co-exist, spruce usually assumes dominance in the stand. It is not only the larger of the two trees but is also more abundant and longer lived (Oosting, 1956). Spruce-fir communities are usually stable because of exclusive reproduction and the relative absence of major disturbances such as fire, insect and wind throw.

Melting snows and frequent summer rains reduce the chances of forest fires occurring in the spruce-fir (Marr, 1961). However, the large volume of dead woody material and the highly developed verticle continuity of fuels usually present in these communities creates extremely hazardous conditions during periods of high fire danger. Rates of spread can vary

from low to high in spruce-fir communities depending on fuel continuity, slope, wind and fuel moisture (Barrows, 1951a). The usually moist conditions and deep duff increase the likelihood of hold-over fires. When conditions are dryer high intensity fires can develop causing crowning and spotting (Barrows, 1951a).

There are approximately 1,217,700 acres of spruce-fir in the five Front Range National Forests (Table 4).

Fires in the spruce-fir zone result in the establishment of subclimax forests of lodgepole pine, quaking aspen and Douglas-fir (Daubenmire, 1943). Lodgepole pine communities are wide-spread in the northern half of the State (Costello, 1964), mainly in the lower half of the subalpine zone and upper montane zone (Zuck, 1974). Aspen communities are also prevalent throughout the subalpine and montane zones. In the southern part of the State aspen is the most common pioneer species following fire (Oosting, 1956). Elsewhere aspen is favored on the moist sites and following light burns whereas lodgepole is favored on dry sites and after more intense burns (Daubenmire, 1943). Near the timberline climax spruce-fir forests are replaced directly by spruce-fir forests (Oosting, 1956). This process is exceedlingly slow as evidenced by burns such as the one at Vail Pass on the Arapahoe and White River National Forests.

Lodgepole pine is an intolerant tree requiring bare soil to regenerate (Smith, 1962). This coupled with serotinous cones, makes lodgepole pine ideally suited to burned areas. Fire has been the dominant force in establishing lodgepole pine forests (Clements, 1910). Lodgepole pine often grows in such dense stands that the forest floor is composed exclusively of litter (Moir, 1969). In more open stands the usual understory includes heartleaf arnica, grouse whortleberry, common juniper and kinnikinnic (Costello, 1964).

Because of short summers with frequent rain showers fires in lodgepole pine are not as common as would be expected in such a hazardous fuel. However,

the presence of lodgepole pine is an indicator of past fires (Clements, 1910) and the type can be extremely hazardous during short drying periods. Rates of spread vary depending upon stand conditions. In more open stands fires generally spread in surface fuels. In dense dog-hair stands fires are more likely to spread directly through the crowns creating high intensity fires (Lynch, 1974).

Although lodgepole pine is normally considered successional some stands appear to be stable climax communities at present (Moir, 1969). However, the extensive stands of lodgepole pine in the northern half of the State are mostly the result of fire. There are approximately 918,400 acres of lodgepole pine in the five Front Range National Forests (Table 4).

Aspen stands are common throughout much of Colorado. They are commonly found on areas which have been disturbed by fire, logging and avalanche (Lynch, 1974). Aspen is susceptable to a host of insects and diseases. Fires often cause high mortality to standing trees either directly by heating or indirectly by reducing resistance to insects and diseases. However, because of suckering it reproduces prolifically following fire (Smith, 1962). Aspen communities are characterized by rank herbaceous understories of such species as golden banner (*Thermopsis divaricarpa*), strawberry (*Fragaria ovalis*), yarrow (*Achillea lanulosa*), nodding brome (*Bromus anulus*) and bluegrass (*Poa* spp.) (Zuck, 1974).

In aspen stands luxuriant vegetation, usually moist conditions and low flammability provide a low potential for wildfire (Lynch, 1974). However, during a short period in the fall when the herbaceous vegetation is cured and snow has not yet compacted the litter fires can spread rapidly.

Extensive areas of aspen throughout the Front Range provide important wildlife habitat and an aesthetically pleasing visual resource. There are approximately 475,000 acres of this resource in the five Front Range National Forests (Table 4).

The alpine zone is the area above the upper limits of tree growth. Timberline occurs between 11,500 feet in the northern and 12,000 feet in the southern parts of the State. Although fires do occur in the alpine zone they are of little importance in an analysis of hazard and risk.

ANALYSIS OF FOREST FIRE HAZARDS

Fire hazard refers to the material that burns--the fuels of the forest complex. In this research an analysis has been made of fire performance in each major forest cover type and in each specific fuel type within the cover types. Hazard characteristics have been examined in the various elevation zones of the Front Range country. In addition, an inventory and analysis of specific features of fuels has been performed for a selected fire hazard area.

Forest Cover Types

Analysis of reports of fires occurring in five National Forests permitted examination of hazard characteristics in major cover types of the Front Range. During a ten-year study period, 1960-1969, a total of 1563 fires burned 9181 acres in the eight cover types occurring in these National Forests (Table 2). The peak fire occurrence and the largest area burned was on the Pike National Forest.

In the study area 91 percent of the fires and 98 percent of the area burned occurred in the lodgepole pine, ponderosa pine, spruce-fir, Douglas-fir and brush-grass cover types (Table 3). The deciduous, subalpine and pinyon-juniper cover types have very small numbers of fires and area burned in the Front Range National Forests.

Ignitability of fuels and probability of fires spreading to large size are important indicators of the severity of fire hazards in the various forest cover types. On the basis of the ten-year study period, the average ignition rate was 269 fires per million acres in all cover types (Table 4). An average of 10 fires per million acres reached Class C or larger size (10 or more acres). During the ten-year period 3.7 percent of all fires reached Class C or larger size and accounted for 93 percent of the total area burned.

Table 2. Number of Fires and Area Burned by Forest Cover Type in Front Range National Forests, 1960-1969.

Forest Cover Type	Data	National Forest					Front Range Total
		Arapaho	Pike	Rio Grande	Roosevelt	San Isabel	
Lodgepole Pine	No. Fires	71	30	6	71	30	208
	Area Burned	86	7	77	1254	141	1565
Ponderosa Pine	No. Fires	3	407	32	141	81	664
	Area Burned	23	3163	7	464	98	3755
Spruce-Fir	No. Fires	44	36	39	20	23	162
	Area Burned	1607	6	380	28	284	2305
Douglas-fir	No. Fires	2	111	32	23	38	206
	Area Burned	2	444	2	3	2	453
Brush-Grass-Sage	No. Fires	21	68	32	28	35	184
	Area Burned	248	162	246	65	238	959
Deciduous	No. Fires	7	14	19	1	14	55
	Area Burned	16	55	57	0	6	134
Sub-alpine	No. Fires	8	25	12	10	12	67
	Area Burned	0	0	4	0	2	6
Pinyon-Juniper	No. Fires	0	0	8	0	9	17
	Area Burned	0	0	4	0	0	4
Forest Total	No. Fires	156	691	180	294	242	1563
	Area Burned	1982	3837	777	1814	771	9181

Table 3. Fire Occurrence and Area Burned by Forest Cover Types in Front Range National Forests, 1960-1969. (Basis 1563 fires.)

Forest Cover Type	No. of Fires	% of Fires	Acres Burned	% of Burn
Lodgepole Pine	208	13.3	1565	17.1
Ponderosa Pine	664	42.4	3755	40.9
Spruce-Fir	162	10.4	2305	25.1
Douglas-fir	206	13.2	453	4.9
Brush-Grass	184	11.8	959	10.4
Deciduous	55	3.5	134	1.4
Sub-Alpine	67	4.3	6	0.1
Pinyon-Juniper	17	1.1	4	0.1
Total - All Cover Types	1563		9181	

Table 4. Number of Fires per Million Acres by Cover Type in Front Range National Forests, 1960-1969. (Basis 1563 fires.)

Forest Cover Type	Acres in Type	Total No. of Fires per Million Acres	No. of Class C or Larger Fires per Million Acres (2)
Lodgepole Pine	918,400	226	6.53
Ponderosa Pine	503,000	1320	33.8
Spruce-Fir	1,217,700	133	4.1
Douglas-fir	497,200	414	10.1
Deciduous	475,000	116	8.4
Other Cover Types (1)	2,203,000	122	9.5
Total - All Types	5,814,300	269	10.0

(1) Includes brush-grass, pinyon-juniper, non-commercial and sub-alpine species.

(2) Fires greater than 10 acres in size.

Ponderosa pine clearly leads all other cover types in ignition rates and large fire occurrence (Table 4). In this type the average annual ignition rate of 132 fires per million acres is 390 percent greater than the average for all cover types. However, this ignition rate is strongly influenced by risk factors, expecially lightning risk, as explained later. Large fire occurrence (Class C or greater) in ponderosa pine is 238 percent greater than the average for all cover types and 234 percent greater than in its nearest competitor--the Douglas-fir type.

The overall fire hazard of the ponderosa pine type is influenced by several factors. The open canopy characteristic of the type permits surface fuels to receive more solar radiation and become dryer and more flammable. Situated mainly in medium elevation zones, the ponderosa pine type exists in a region of relatively higher temperature and lower relative humidity than the lodgepole pine and spruce-fir types.

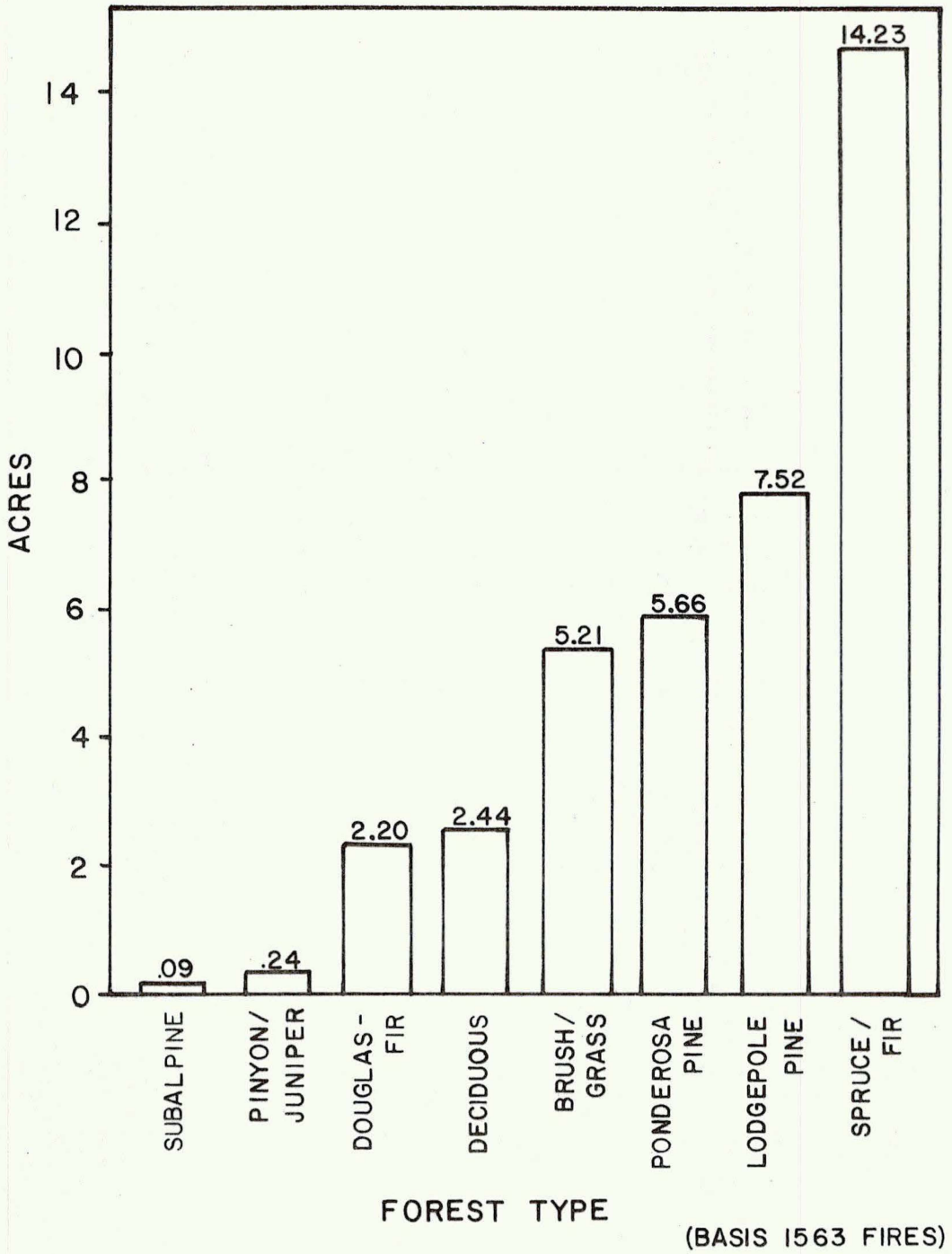
Other characteristics of Front Range forest cover types are important in evaluation of fire hazards. Very large areas of fuels exist in the spruce-fir, lodgepole pine, Douglas-fir and brush-grass types. As shown in Figure 4 the spruce-fir type leads all other types in average size per fire. The Front Range high country contains vast areas of continuous fuels in the spruce-fir type. Under the relatively rare occurrence of drouth and extreme fire danger in the spruce-fir zone there is a potential for large and severe fires. To a lesser extent this potential also exists in the lodgepole pine type.

Topography

Topographic factors, including elevation zones, aspect and slope steepness are interrelated to forest cover type in analyses of fire hazards. In this exploratory study the primary emphasis has been on elevation zones as descriptors of fire environment.

Figure 4

AVERAGE SIZE PER FIRE BY COVER TYPE IN FRONT RANGE NATIONAL FORESTS 1960-1969



In the Front Range National Forests 6.3 percent of the fires in the 5501 to 6500 foot elevation zone reach sizes greater than 10 acres (Table 5). This is about double the rate of large fire occurrence found in higher elevation zones. All of the large fires in the low elevation zone occurred in the ponderosa pine and brush-grass types. However, it should be noted that large fires in these two cover types occurred in each of the four major elevation zones. Moreover 70 percent of all class C or larger size fires occurred in the ponderosa pine and brush-grass types.

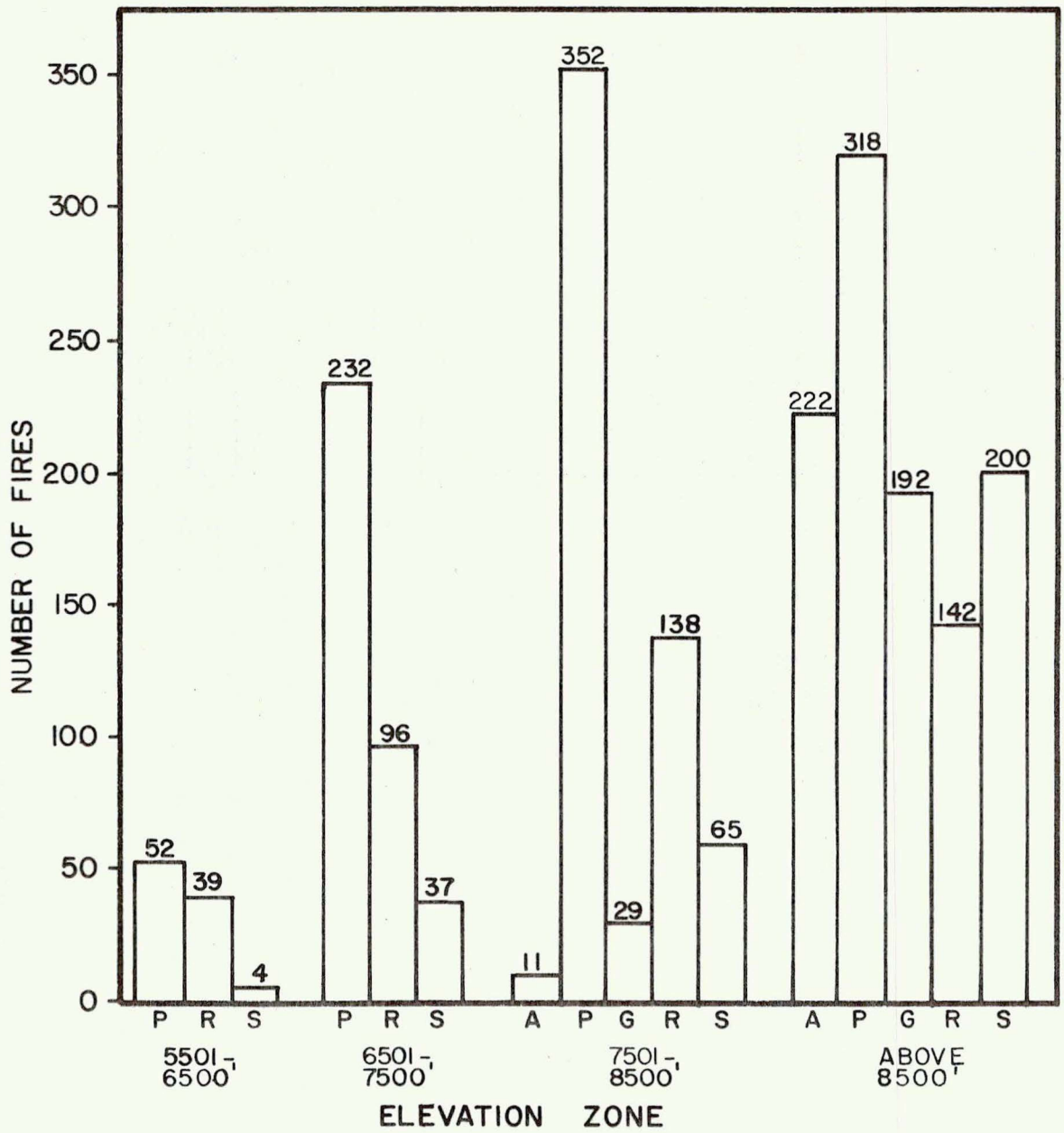
Peak fire occurrence in four of the five Front Range National Forests occurs above 8500 feet (Figure 5). In the Pike National Forest the peak occurrence is the 7501-8500 elevation zone. Data is not available on the acreage in each elevation zone but a general examination of the topography indicates that the greatest area is above 8500 feet. It is estimated that ignition rates per million acres are higher in the fuels below the 8500 foot level. However, from a viewpoint of total fire load the hazards above 8500 feet require careful attention. During the period 1960-1972, 1074 fires occurred in this zone. Of these fires, 42 reached class C or larger size. This is 55 percent of the large fires in the Front Range National Forests. Moreover, 6 of the 8 fires reaching sizes greater than 300 acres were at elevations above 8500 feet.

Table 5. Distribution of Class C or Larger Size Fires by Elevation Zones and Forest Cover Types in Front Range National Forests, 1960-1972. (Basis 2128 fires).

Forest Cover Type		Elevation Zones 5501-6500 feet	6501-7500 feet	7501-8500 feet	Above 8500 feet
Lodgepole Pine	#	0	0	0	6
	%	0	0	0	2.5
Ponderosa Pine	#	3	10	7	5
	%	5.0	3.6	1.8	2.4
Spruce-Fir	#	0	0	0	6
	%	0	0	0	3.0
Douglas-fir	#	0	1	2	0
	%	0	2.4	2.4	0
Brush-Grass	#	3	1	6	18
	%	11.5	3.1	11.3	13.6
Deciduous	#	0	0	1	4
	%	0	0	14.3	6.4
Pinyon-Juniper	#	0	0	0	2
	%	0	0	0	12.5
Sub-Alpine Species	#	0	0	0	1
	%	0	0	0	1.2
Total All Types	#	6	12	16	42
	%	6.3	3.3	2.7	3.9

Figure 5

NUMBER OF FIRES BY ELEVATION ZONE
IN FRONT RANGE NATIONAL FORESTS 1960-1972



NATIONAL FOREST

A = ARAPAHO
P = PIKE
G = RIO GRANDE
R = ROOSEVELT
S = SAN ISABEL

Fuel Types

For many years the U.S. Forest Service fuel classification and mapping system has evaluated fuel complexes according to the characteristics influencing the rate-of-spread of fires and resistance to fire control efforts. The rate of spread classifications provide an important method for general evaluation of fire hazards. Four classes are recognized and are given adjective descriptions of low, medium, high and extreme. In the original development of this classification system by Hornby (1933), the four fuel types in the northern Rocky Mountain area were estimated to have average fire rate-of-spread levels as follows (Hornby, 1933):

Fuel R/S Type	Perimeter Increase per Hour
Low	4 to 6 chains
Medium	6 to 8 chains
High	8 to 10 chains
Extreme	10 to 14 chains

Later studies by Barrows based upon fires in the northern Rocky Mountains showed the following average rate-of-spread characteristics (Barrows, 1951b):

Fuel R/S Type	Average Initial Perimeter Increase Per Hour At Burning Index of 70	Maximum Perimeter Increase Per Hour For 85% of Fires At Burning Index of 70
Low	4.5 chains	8.0 chains
Medium	6.0 chains	10.0 chains
High	13.0 chains	28.0 chains
Extreme	18.0 chains	35.0 chains
Flash	33.0 chains	65.0 chains

In this study the flash classification was added to better describe rate-of-spread in cured dense stands of cheat grass and bunch grass and in heavy logging slash with dry needles remaining on limbs.

Examination of fire performance in Colorado forests provides insight into the effectiveness of fuel rate-of-spread classifications as descriptors of fire hazards. Data is not available on the acreage in each of the four fuel rate-of-

spread types in the Front Range national forests. However, study of 1563 fires occurring during the 1960-1969 period shows that 98 percent were in the low, medium and high fuel types. Only 34 fires occurred in the extreme fuel type. The flash fuel type classification is not used in Colorado.

Fuel rate-of-spread classifications have proved to be a useful method of fire hazard evaluation in the Front Range national forests. In these forests 68 percent of all Class C or larger fires and 62 percent of the fires burning more than 300 acres occurred in the high and extreme fuel types. As shown in Figure 6 the occurrence of Class C or larger fires varied from 1.28 percent in the low fuel type to 14.71 percent in the extreme type. Only minute differences in large fire potential were found between the low and medium types. However, large fire potential was found to be more than five times greater in the high than in the low or medium classifications. The very small number of fires in the extreme fuel type indicates that there have been limited situations warranting this classification.

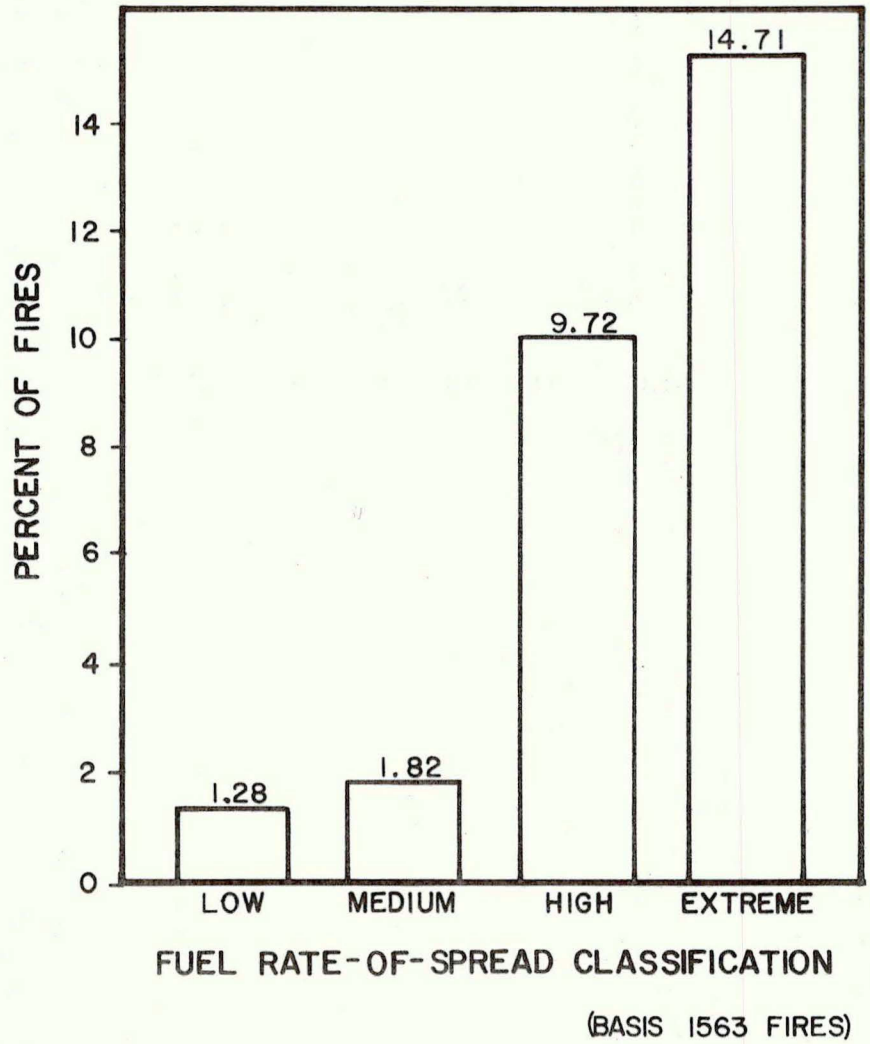
The large fire potential in Colorado Front Range fuels appears to be somewhat less than in other locations in Rocky Mountain forests. Studies in the eastern zone national forests of Montana have shown a higher percentage of fires reaching class C or larger size in each of the four fuel rate-of-spread classifications (Barrows, 1951b). In the six eastern Montana national forests during a nine year period the percent of large fires was as follows:

Fuel R/S Type	Percent of Class C or Larger Fires
Low	3.7%
Medium	6.5%
High	15.0%
Extreme (Grass)	23.0%

During the 1960-1969 period 9181 acres were burned in the Front Range national forests (Table 6). The high rate-of-spread fuel type accounted for 45 percent of this burn. However, it is interesting to note that while 42

Figure 6

PERCENT OF FIRES REACHING CLASS C OR LARGER SIZE IN EACH FUEL RATE-OF-SPREAD CLASSIFICATION IN FRONT RANGE NATIONAL FORESTS 1960-1969



percent of the total Front Range area burned was in the Pike National Forest, 65 percent of that forest's burn was in the low fuel type. This high acreage total in the low fuel type resulted mostly from one 2,427 acre man-caused fire in ponderosa pine.

Table 6. Acres Burned By Fuel Type In Front Range National Forests, 1960-1969.

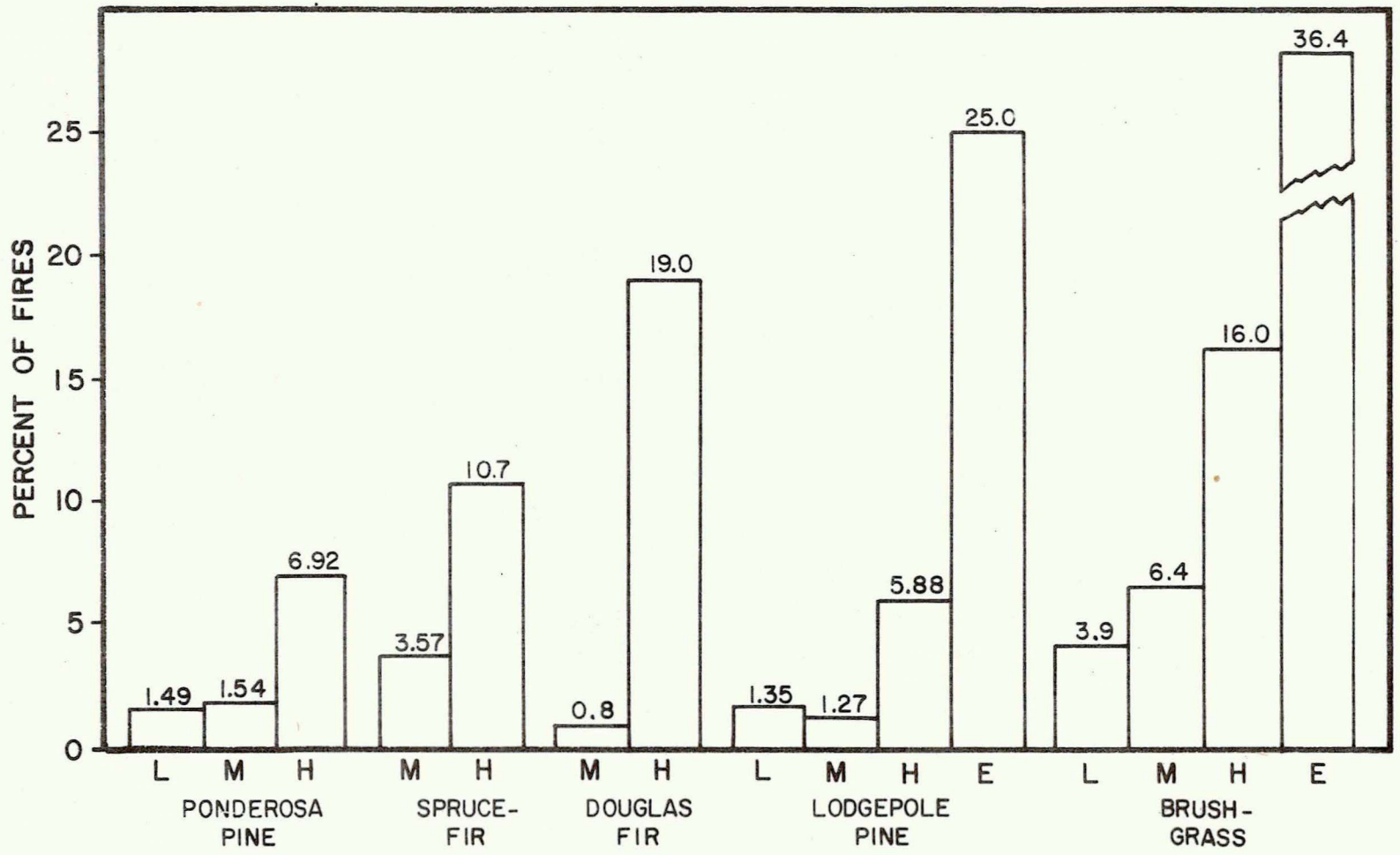
	Rate of Spread				
	Low	Medium	High	Extreme	Total
Arapaho	36	642	1056	248	1982
Pike	2515	273	1041	8	3837
Rio Grande	119	56	602		777
Roosevelt	496	371	946	1	1814
San Isabel	42	169	480	80	771
Total	3208	1511	4125	337	9181

Examination of fire performance by fuel type within each forest cover type provides a further means of evaluating methods for description of fire hazards. Analysis of the fires in Front Range national forests shows that in each major forest cover type the system for classifying fire rate-of-spread has been generally accurate (Figure 7). Without exception a significantly greater number of fires in the high and extreme fuel types reach Class C or greater size in each of the five major forest cover types of the Front Range.

In the integrated analysis of hazards in forest cover types and fuel types data was available from fires in eight cover types. The lodgepole pine, ponderosa pine, Douglas-fir, spruce-fir and brush-grass types accounted for 91 percent of the fires (Table 3) and 86 percent of the Class C or larger fires (Table 5). There were not any Class C or larger fires in the sub-alpine and pinyon-juniper cover types. In the spruce-fir and Douglas-fir cover types Class C or larger fires did not occur in either the low or extreme fuel rate-of-spread types. In the ponderosa pine type, in spite of the previously discussed high ignition rates and large area burned, no large fires were reported

Figure 7

PERCENT OF CLASS C OR LARGER FIRES BY FOREST COVER TYPE AND FUEL COVER IN FRONT RANGE NATIONAL FORESTS 1960-1969



in extreme rate-fo-spread fuels. In the deciduous cover type (primarily aspen) only four Class C or larger fires were reported. All of these fires occurred during the dormant season when leaves were cured. These fires could be expected to spread primarily in dry surface fuels not normally existing in this cover type during the summer period.

These preliminary studies indicate that evaluation of the combination of forest cover type, fuel type and topography provide an effective system for rating of fire hazards. Fuel rate-of-spread classifications are effective descriptors of fire hazard although the results to date indicate general inability to recognize major differences between medium and low calssifications. The high rate-of-spread fuel classification has been clearly identified in each of the five major cover types. Analysis of fire performance in the extreme rated fuel types of the lodgepole pine and brush-grass types show good ability to recognize potentials for large fires.

Topographic elements of fire hazard require more detailed examination. Future studies will include an analysis of aspect and slope steepness in addition to elevation zones.

Inventory and Analysis of Fuels

The fuel inventory field work centered in the Front Range forests west of Boulder, Colorado in Townships T1N-R71W, T1N-R72W, and T1S-R71W. Eight stands were inventoried during eight weeks of field study in July, August and September.

An average of three hours per day were spent traveling to and from the study area. Approximately seven hours per day were spent actually locating and inventorying stands. A total of thirty-four man-days of actual field work were performed. This constituted approximately 4.25 man-days time for locating and inventorying each stand. However, because this was the first study of its kind performed at lower elevations in the Front Range forests of Colorado some experimentation with the transect length needed to adequately sample fuels was performed. After sampling four stands adequacy of sample tests revealed that

some modifications in transect length were needed. This required some resampling in the four stands. As a result the first four stands were less efficient time-wise, than the last four.

The length of the transect required to adequately sample each fuel size class is dependant upon the variation in that class. Adequacy of sample tests performed on the first four stands revealed that the 27.2 foot transect, which had been successfully used in U.S. Forest Service Region I (Mutch and Aldrich, 1972) was not long enough to adequately sample the variation in the over-three-inch size class. Brown (1974) suggests that acceptable results can usually be attained by using a transect long enough to assure at least one intersection on 75% of the transects. Using this criteria, field tests were conducted on the four stands to determine the minimum length of transect which would adequately sample fuels over 3 inches in diameter. The test consisted of four test plots of 2 to 6 fifty-foot transects each. The number of intersections on each fifty-foot segment was recorded and the minimum number of fifty-foot intervals determined. The transects were lengthened in increments of fifty feet to simplify sampling. Once the length had been determined for each stand the plots were reseampled for the fuels greater than three inches. Similar tests for minimum transect length were conducted on subsequent stands. Table 7 lists the length of plot transect which was used in each stand.

An alternative to lengthening the transect is to increase the number of inventory plots in each stand. However, this may not always be a viable alternative. For example, adequacy of sample tests revealed that by using the original 27.2 foot transect 79 plots were needed in stand 1 and 227 plots were needed in stand 2 if a 20 percent error was desired. By increasing the number of plots in order to adequately sample the larger fuels you over sample the finer fuels. This is more time-consuming than lengthening the transect. Therefore, it is better to let the finer fuels dictate the number of plots in each stand and to let the variability in the larger fuels dictate the transect

Table 7. Transect and Plot Information

Stand #	Forest Cover Type	# of Transects	# of Plots	Distance Between Plots	Plot Transect Length
1	Ponderosa	5	25	3 chains	200 ft
2	Mixed Conifer	3	21	3 chains	200 ft
3	Douglas-fir	3	22	2 chains	100 ft
4	Ponderosa	2	20	4 chains	200 ft
5	Ponderosa	2	20	4 chains	300 ft
6	Mixed Conifer	4	20	2 chains	50 ft
7	Ponderosa	3	21	3 chains	200 ft
8	Mixed Conifer	3	21	3 chains	200 ft
	TOTAL	24	169		

Table 8. Fuel Loadings and Percent Error (PE).

Stand #	Forest Cover Type		Woody Fuel Loadings (Tons/Ac) and Percent Error 0-.25	.25-1.0	1.0-3.0	3.0+	Total
1	Ponderosa	wt.	.33	.982	1.104	.747	3.168
		PE	18	15	38	30	
2	Mx.Conifer	wt.	.37	1.876	3.609	.933	6.790
		PE	20	21	32	52	
3	Douglas-fir	wt.	.92	.977	1.082	2.080	5.060
		PE	15	21	15	32	
4	Ponderosa	wt.	.13	1.044	4.122	1.749	7.044
		PE	30	26	42	39	
5	Ponderosa	wt.	.05	.508	.309	.916	1.788
		PE	19	29	31	36	
6	Mx. Conifer	wt.	1.23	1.916	2.864	10.644	16.674
		PE	12	18	13	17	
7	Ponderosa	wt.	.10	.898	3.095	1.032	5.125
		PE	27	18	36	23	
8	Mx. Conifer	wt.	.33	1.766	5.753	1.501	9.347
		PE	38	17	47	39	

PE - Percent Error - Standard Error of the Estimate/Mean of the Estimate.

length. Table 7 shows the number of plots and the length of the transect used in each stand.

The degree of accuracy desired will greatly effect the number of plots and the length of the transect. Twenty percent error is sufficient for most fuel appraisal situations (Brown, 1974). Table 8 shows the weight of dead woody fuel in each of the four fuel size classes and the percent error for each of the four fuel size classes and the percent error for each fuel loading. An average of 21 plots were used on each of the eight stands (Table 7) and the percent errors (Table 8) indicate adequate results on the finer fuels except in stands 4, 5, and 8. In stand #8 good results were attained in the .25 to 1.0 inch size class but the 38 percent error in the 0 to .25 inch size class is high. Examination of the field data revealed that 94 intersections occurred on one plot in the stand. This was 40 percent of the total number of 0 to .25 inch intersections in the stand. The average number of 0 to .25 intersections in the stand was 7. If the 94 intersections is viewed on an outlier the error is reduced to 16 percent.

The high percent error on plots 4 and 5 may be partially explained by the fact that these stands are open grown savanna stands. Due to the scarcity of woody fuels in these open stands either more plots should be measured or the 6.8 foot transect should be lengthened. Another alternative would be to use an area fuel sampling technique in open grown stands.

With the exception of stand 6 the percent errors in the two larger size classes are high. This is indicative of the high degree of variability in the larger size classes. A large sampling error results when many of the transects do not intersect fuel particles (Brown, 1974). The sampling variance is also increased when most of the sample planes have one or two intersections and a few have seven or eight intersections. This situation occurs when a few transects cross the crowns of large downed snags. Therefore, if a high degree

of accuracy is needed and the fuels are discontinuous, which is a common situation in the Front Range ponderosa pine, transects greater than two hundred feet will probably be necessary. For most fire prediction situations in open ponderosa pine a high degree of accuracy in the over three inch size class is probably not important enough to warrant the additional sampling.

One factor which may have contributed to the scarcity of larger sized fuel particles in the closed stands is the fact that much of the study area had been logged in the late 1800's, presumably, for mine timbers. All stands except 4 and 5 had been selectively logged and burned leaving only scattered remnants of the original forests. As a result the forest floor was relatively free of larger sized fuels.

The field study also included classifying the stands according to three fuel classification systems. Table 9 shows a breakdown of the three classification systems for each stand. Wildfire Hazard Classes were taken directly from the Wildfire Hazard Area Maps. Fuel Models were determined from a dichotomous key of National Fire Danger Rating System Fuel Models (Deeming et al., 1972). The work by Barrows (1951a) and Fahnestock (1970) was used as field guides for evaluating rate of spread. The rates of spread reported in Table 9 should not be viewed as constant within a Hazard class or Fuel Model. Slope and fuel bed continuity effected the rate of spread classification given the stands and do not represent definitive values. To compensate for seasonal variation in rate of spread the values reported in Table 9 are projected maximum values for fuel beds which are cured but have not been compacted by the first snowfall.

The general stand measurements are presently being analyzed to determine average stand age, stand history, average basal area, site index, and average distance to the base of the living crown. An in-depth analysis of fuel loadings and their relationship to the general stand measurements is presently being performed and will be reported in the Phase II Report.

Table 9. Fuel Classifications

Stand Number	Forest Cover Type	CSFS H.C.	NFDR F.M.	Fuel Type
1	Ponderosa Pine	C	C	MM
2	Mixed Conifer	C	H	MM
3	Douglas-fir	C	H	MM
4	Ponderosa Pine	A	A	LL
5	Ponderosa Pine	A	A	ML
6	Mixed Conifer	C	H	MH
7	Ponderosa Pine	B	C	LM
8	Mixed Conifer	B	C	LM

CSFS H.C. - Colorado State Forest Service Wildfire Hazard Area Mapping Classification.

NFDR F.M. - National Fire Danger Rating System Fuel Model.

Fuel Type - L - Low; M - Medium; H - High; E - Extreme.

ANALYSIS OF FOREST FIRE RISKS

Risk Characteristics

Fire risk refers to the activities causing ignition of forest fires. In this study risks are subdivided into two broad categories -- lightning and man. The investigations have been centered on risk patterns and the environmental situations related to the occurrence of lightning and man-caused forest fires. It was not the objective of this preliminary study to investigate the nature and distribution of specific kinds of man-caused fires. The available fire and social data was inadequate for an in-depth investigation of man-caused fire risks.

Lightning Fires

In the state of Colorado during the 1946-1973 period lightning caused 7,242 forest fires. This is 35 percent of the total fire occurrence and amounts to an annual average of 259 lightning caused forest fires. The total lightning fire load handled by the State and federal forest protection agencies has increased during the 28-year period. This change is produced by an increase of some eight million acres in the area protected from fires. The more recent lightning fire occurrence data may also reflect increased capabilities by the forest protection agencies for lightning fire detection.

As shown by Figure 8 an annual average of 441 lightning fires occurred in the State during the 1970-1973 period. The peak annual occurrence recorded during the 28 year period was 641 lightning fires in 1972.

In the Front Range National Forests 48 percent of the fires were lightning caused during the 1960-1972 period. The average annual occurrence rate is 11.71 lightning fires per million acres. The most intense lightning fire areas are on the Pike and Roosevelt National Forests. As shown in Figure 9 the lightning fire occurrence rate per million acres is nearly three times greater on the Pike National Forest than the Front Range average.

Figure 8

AVERAGE ANNUAL NUMBER OF FIRES IN COLORADO
BY FOUR YEAR PERIODS
SUBDIVIDED BY MAN CAUSED AND LIGHTNING CAUSED

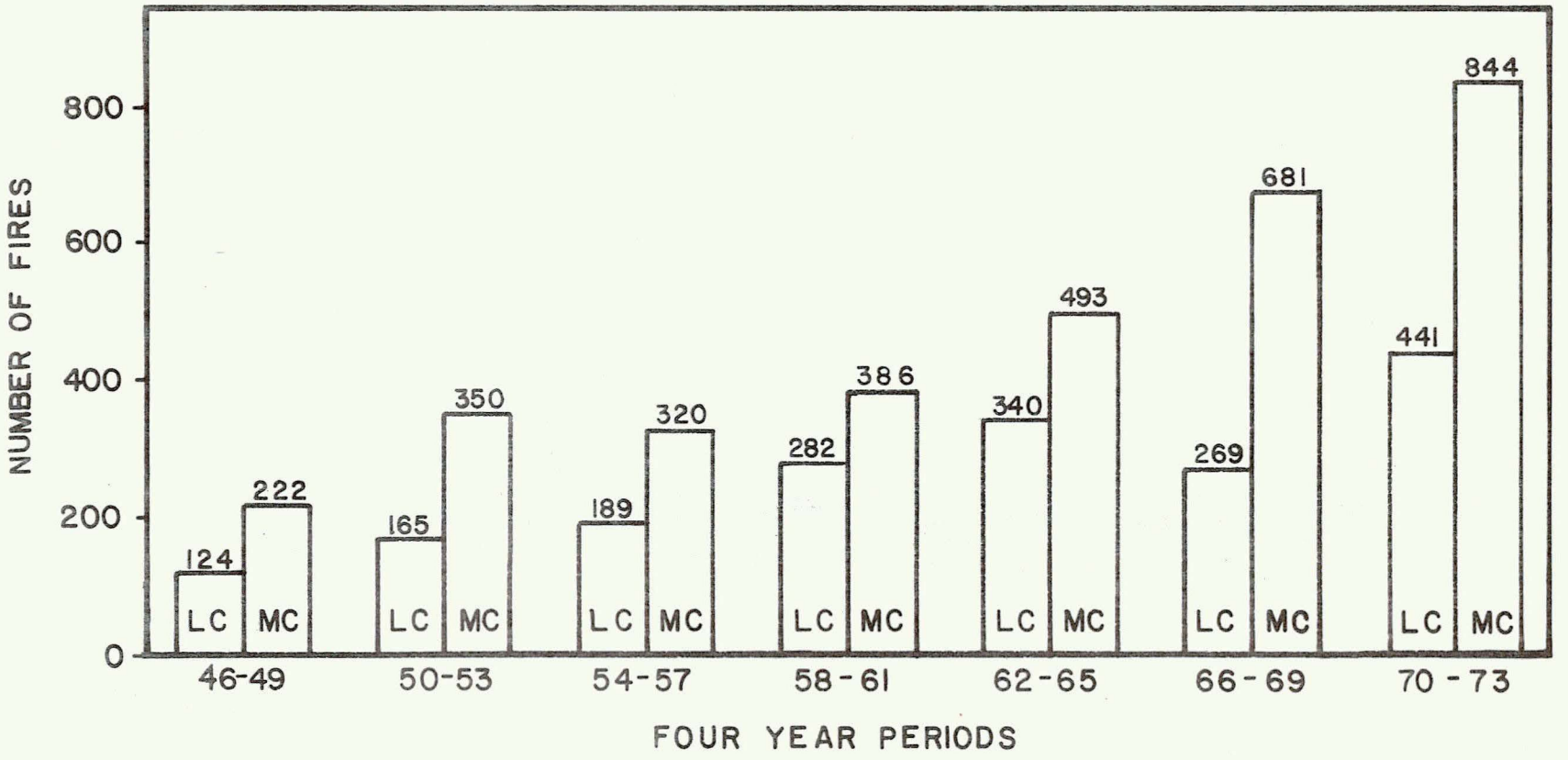
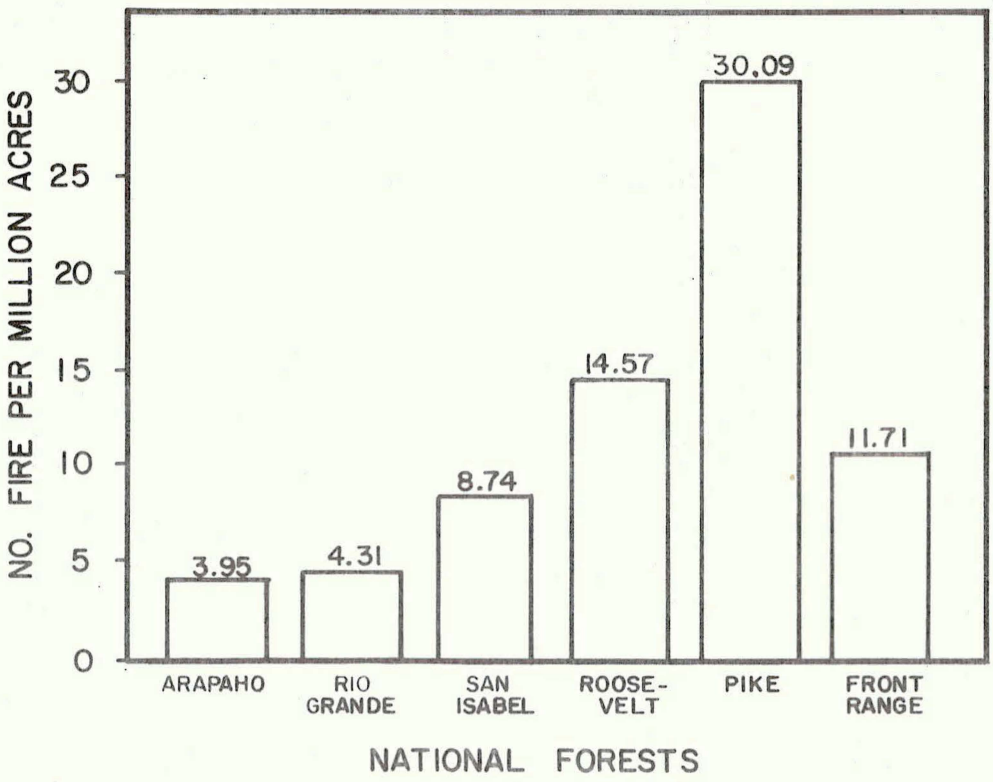


Figure 9

AVERAGE ANNUAL NUMBER OF LIGHTNING FIRES PER MILLION ACRES IN FRONT RANGE NATIONAL FORESTS, 1960-1972



Lightning fires occur in all elevation zones in the Front Range forests. However, the available data indicates that peak occurrence per unit area is in the middle elevation zones. Data on the exact acreage in each elevation zone was not available for this study. The largest area is estimated to be above 8500 feet. Nevertheless, the peak lightning fire occurrence on the two leading lightning fire forests, the Pike and Roosevelt, is found in the 7501 to 8500 foot elevation zone (Table 10). This feature of lightning risk may be influenced by a combination of fuel and fire weather characteristics in the medium elevation zones.

Table 10. Lightning Fire Occurrence by Elevation Zones in Front Range National Forests, 1960-1972.

National Forest	Elevation Zone				All Zones	
	5501 to 6500'	6501 to 7500'	7501 to 8500'	Above 8500'	No.	%
Arapaho			5	51	56	24
Pike	9	142	196	155	502	53
Rio Grande			17	93	110	50
Roosevelt	16	51	79	59	205	50
San Isabel	3	22	34	79	138	46
Front Range Total	28	215	331	437	1011	48

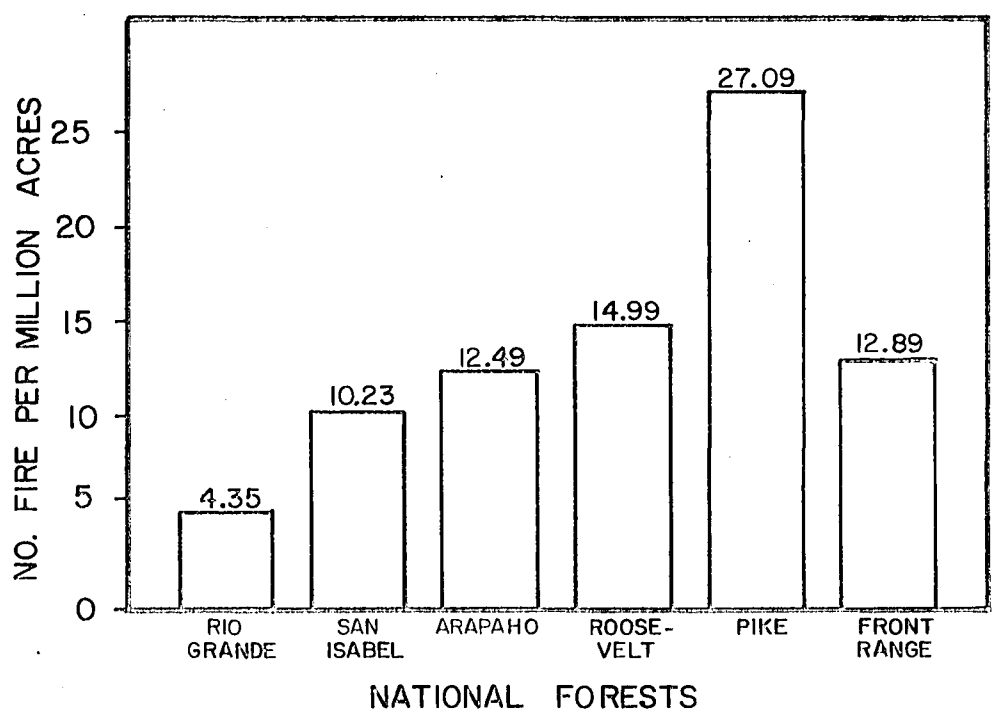
Man-Caused Fires

In the State of Colorado there has been a 380 percent increase in the number of man-caused fires between the 1946-1949 and 1970-1973 periods (Figure 8). During the same period the increase in man-caused fires in Front Range National Forests was 118 percent.

The occurrence rate for man-caused fires in the Front Range National Forests during the 1960-1972 period was 12.89 fires per million acres. Following the

Figure 10

AVERAGE ANNUAL NUMBER OF MAN-CAUSED FIRES PER MILLION ACRES IN FRONT RANGE NATIONAL FORESTS, 1960-1972



pattern for lightning fires this peak occurrence of man-caused fires was found on the Pike and Roosevelt National Forests (Figure 10). However, unlike lightning fires, in each Front Range National Forest the greatest number of man-caused fires occurred in the highest elevation zone. Fifty-seven percent of all man-caused fires occurred in the elevation zone above 8500 feet (Table 11).

Table 11. Man-Caused Fire Occurrence by Elevation Zones in Front Range National Forests, 1960-1972.

National Forest	Elevation Zone				All Zones	
	5501 to 6500'	6501 to 7500'	7501 to 8500'	Above 8500'	No.	%
Arapaho			6	171	177	76
Pike	43	90	156	163	452	47
Rio Grande			12	99	111	50
Roosevelt	23	45	59	83	210	50
San Isabel	1	12	31	121	165	54
Front Range Total	67	147	264	637	1115	52

Analysis of man-caused fire risks requires investigation of the type and density of uses of forest areas. In particular, it is desirable to investigate recreation use in relation to fires that may be related to this use. Unfortunately, a uniformly collected long term data base on recreation use is not available. However, in an exploratory effort to study the recreation generated fire load an analysis was made of smoker and camper fires in relation to numbers of recreation visits.

During the four-year period, 1970-1973, more than 36 million recreation visitor days were estimated by the Forest Service in the Front Range National Forests (Table 12). During this same period a total of 301 smoker and camper caused wildfires occurred in these forests. Assuming that most fires of these

causes are closely related to recreation activities this amounts to an annual average of 8.33 fires per million visitor days.

As shown in Table 12 a large variation occurs between the various national forests in the number of fires per visitor day. Several factors may influence this variation including a variety of social factors, effectiveness of fire prevention programs, accuracy of the fire-cause data and ignitability (hazard) of the fuels. The integrated analysis of fire hazard and risk strongly indicates that fuel ignitability is a major factor in the occurrence of man-caused fires including fires ignited by the activities of recreation visitors to forest areas.

Table 12. Comparison of Recreation Visits with Smoker and Camper Caused Fires, Front Range National Forests, 1970-1973.

National Forest	Recreation Visits (Million Visitor Days)	No. of Fires	No. of Fires per Million Visitors
Arapaho			
4 yr. total	14.98	67	
Annual Average	3.74	16.75	4.47
Pike			
4 yr. total	8.87	116	
Annual Average	2.22	29.0	13.06
Rio Grande			
4 yr. total	2.16	20	
Annual Average	.54	5.0	9.25
Roosevelt			
4 yr. total	4.80	71	
Annual Average	1.32	17.75	14.79
San Isabel			
4 yr. total	5.30	27	
Annual Average	1.32	6.75	5.11
Front Range			
4 yr. total	36.11	301	
Annual Average	9.03	75.25	8.33

INTEGRATED ANALYSIS OF FIRE HAZARDS AND RISKS

Fire Load

At the beginning of our studies in Front Range forests an analysis was made of lightning and man-caused fires during the 28-year period 1946-1973 (Figure 11). This analysis showed an increase in average number of wildfires during each four-year period except 1966-1969. To gain an understanding of the significance of this increase in numbers of fires, it is necessary to examine the factors influencing both ignition probability and the subsequent burning characteristics of the fires. The fire load for a given forest area involves a combination of factors including the nature and frequency of ignitions, the spread rates of fires, and the probability for burning of large areas. These factors, in turn, influence the size and difficulty of fire control operations.

Our studies yielded specific features of fire hazard and risk in Front Range forests. However, application of this information in fire management and land use planning requires a method for integrating hazard and risk factors. Studies of fire history and fuel complexes clearly showed significant features of the fire load for various forest areas. Therefore, we directed efforts toward developing an answer to this question: Can available fire hazard and risk data be used in developing a quantitative rating of fire potential for selected forest areas of the Front Range?

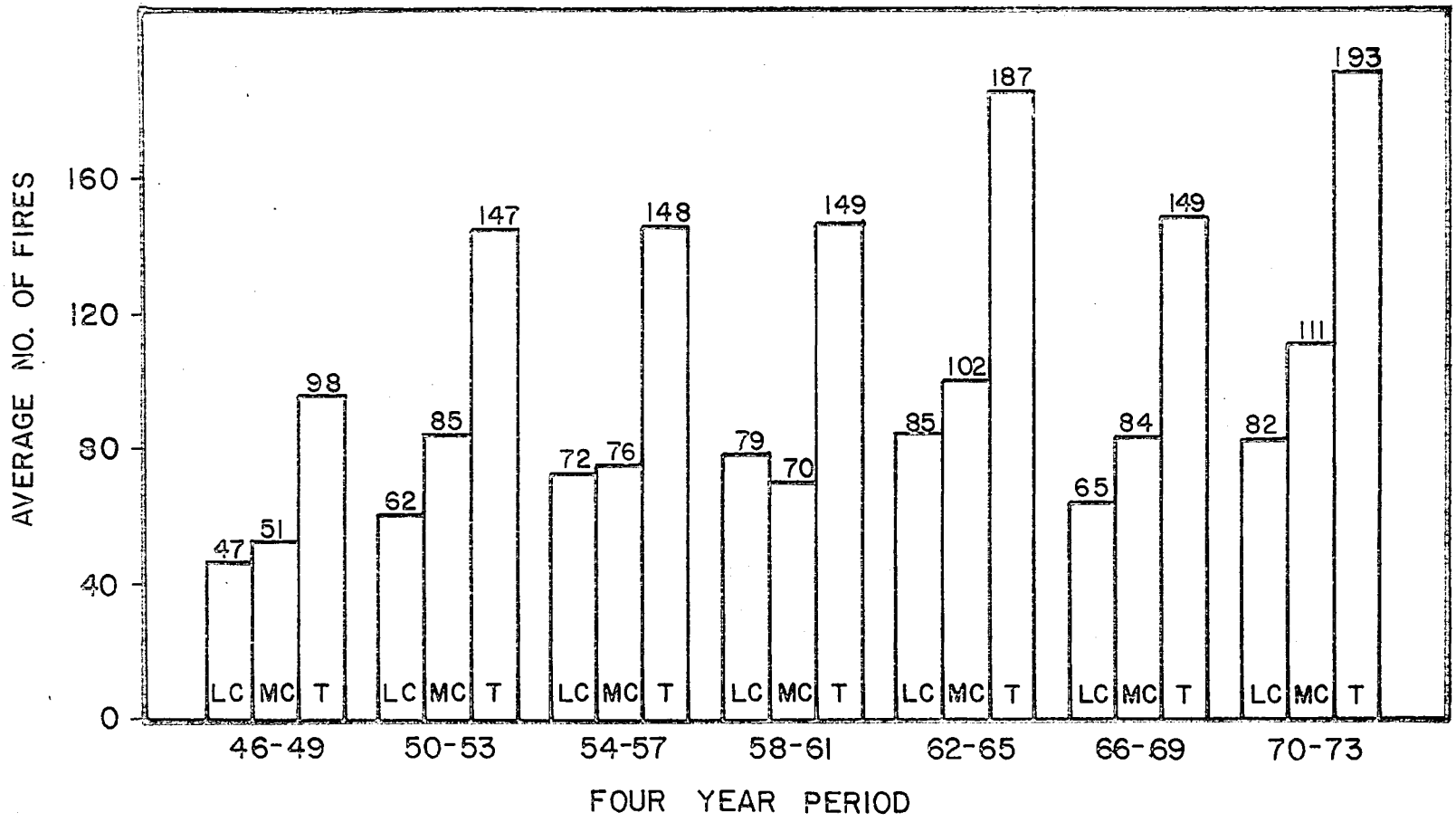
Forest Fire Potential

We define forest fire potential as: "The interrelationship of hazard and risk factors which combine to cause specified levels of fire ignition, spread and magnitude."

In application of this definition of fire potential we examined fire ignition, fire spread and fire magnitude in each major forest type as follows:

Figure 11

AVERAGE NUMBER OF FIRES BY CAUSE AND TOTAL FIRES IN THE FRONT RANGE NATIONAL FORESTS BY FOUR YEAR PERIODS 1946-1973



Fire ignition. Number of lightning and man-caused fires and total fires per million acres.

Fire spread. Number of Class C or larger lightning and man-caused fires and total fires per million acres.

Fire magnitude. Area burned by lightning and man-caused fires and total fires per million acres.

During the period 1960-1973 in Front Range national forests the average ignition, fire spread and fire magnitude levels were 26.9, 1.00 and 157.9 respectively (Table 13). When these three components of fire potential are analyzed by hazard and risk factors a numerical value may be obtained to express fire ignition, spread and magnitude levels per unit area.

The proposed model of forest fire potential assigns equal weight to each of the components of fire ignition, spread and magnitude. The available data indicates that ignition rates are influenced by both the nature and frequency of the fire brand and the flammability of the fuel to specific types of fire brands. For example, the nature of a forest stand may make it either more or less ignitable to specific types of ignition sources. On a per unit area basis ponderosa pine has the highest ignition rates for both lightning and man-caused fires. On the other hand, lodgepole pine, spruce-fir and deciduous forests have high ignition rates from man-caused sources while Douglas-fir has a high rate from lightning (Table 13).

The potential for fire spread (primarily in surface fuels) also varies according to ignition sources. In every forest type in the Front Range man-caused fires exhibit a higher potential for reaching Class C size than do lightning fires. However, the potential for spread to Class C size does not in itself present a full assessment of the potential for large fires. The total environment of a fuel complex including its size and topographic site

Table 13. Analysis of Forest Fire Potential Components in Front Range National Forests (Basis fires 1960-1973)

Forest Cover Type	FOREST FIRE POTENTIAL								
	Fire Ignition[1/]			Fire Spread[2/]			Fire Magnitude[3/]		
	L	MC	Total	L	MC	Total	L	MC	Total
Ponderosa pine	81.9	50.1	132.0	0.60	2.78	3.38	111.9	634.6	746.5
Lodgepole pine	8.3	14.4	22.7	0.00	0.65	0.65	2.2	168.2	170.4
Spruce-fir	4.1	9.2	13.3	0.08	0.33	0.41	48.1	141.2	189.3
Douglas-fir	25.5	15.9	41.4	0.00	1.01	1.01	2.8	88.3	91.1
Deciduous	1.9	9.7	11.6	0.00	0.84	0.84	0.6	27.6	28.2
Other Cover Types	3.6	8.6	12.2	0.05	0.41	0.96	1.6	42.4	44.0
Total All Types	13.0	13.9	26.9	0.09	0.91	1.00	21.0	136.9	157.9

1/ Average Annual Number of Fires per million acres

2/ Average Annual Number of Fires spreading to Class C or larger size per million acres

class C = 10 acres

3/ Average Annual Acres burned per million acres.

must be considered. All of these factors indicate that an evaluation of fire potential should include ignition, spread and magnitude components.

To provide a uniform basis for evaluating interrelated hazard and risk factors each of the fire ignition, spread and magnitude components were normalized on a scale of 100 (Table 14). On the basis of 14 years of wildfire data a maximum value of 100 was assigned to the peak ignition, spread and magnitude averages. Total fire potential was also normalized on a maximum rating of 100 (the average of the three fire potential components).

From this approach to integrated fire hazard and risk analysis the following ranking of total fire potential may be assinged to each major forest cover type in the Front Range national forests:

Forest Cover Type	Fire Potential Ranking[a]		
	Lightning Fires	Man-Caused Fires	Total
Ponderosa Pine	1	1	1
Lodgepole Pine	4	3	3
Spruce-fir	3	5	4
Douglas-fir	2	2	2
Deciduous (Primarily aspen)	6	5	6
Other Cover Types	5	4	5

(a) 1 equals highest ranking

These rankings provide only an approximation of relative fire potential. However, they present a useful insight to the interrelationships of fire hazard and risk. In detailed fire management and land use planning specific features of fuels, weather and topography need to be used in refinement of the fire potential ratings.

Table 14. Fire Potential Ratings for Major Forest Cover Types in Front Range National Forests

Forest Cover Type	Fire Ignition			Fire Spread			Fire Magnitude			Total Fire Potential		
	L	MC	Total	L	MC	Total	L	MC	Total	L	MC	Total
Ponderosa pine	62.05	37.95	100.00	17.75	82.25	100.00	14.99	85.01	100.00	31.60	68.40	100.00
Lodgepole pine	6.29	10.91	17.20	0	19.23	19.23	.29	22.53	22.82	2.19	17.56	19.75
Spruce-fir	3.11	6.97	10.08	2.37	9.76	12.13	6.44	18.91	25.35	3.97	11.88	15.85
Douglas-fir	19.32	12.04	31.36	0	29.88	29.88	.37	11.83	12.20	6.56	17.92	24.48
Deciduous	1.44	7.35	8.79	0	24.85	24.85	.08	3.69	3.77	0.51	11.96	12.47
Other Cover Types	2.72	6.52	9.24	1.48	26.92	28.40	.21	5.68	5.89	1.47	13.04	14.51
Total All Types	9.85	10.53	20.38	2.67	26.92	29.59	2.81	18.34	21.15	5.11	18.60	23.71

L = Lightning Caused Fires

M C = Man-caused Fires

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